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Large-Scale Advanced Propfan (LAP) Program Progress Report

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LARGE-SCALE ADVANCED PROPFAN (LAP) PROGRAM PROGRESS REPORT

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Abstract

The propfan concept, which has been the subject of much research since the mid 1970's, is an advanced propeller concept which maintains the high efficiencies traditionally associated with conventional propellers at the higher aircraft cruise speeds associated with jet transports. The Large-scale Advanced Propfan (LAP) program extends the research done on 2 ft diameter propfan models to a 9 ft diameter article which is representative of the size and construction that would eventually be installed on a new aircraft. This program includes design, fabrication, and testing of both an eight bladed, 9 ft diameter propfan, designated SR-7L, and a 2 ft diameter aeroelastically scaled model, SR-7A. The LAP program is complemented by another NASA sponsored program, the Propfan Test Assessment (PTA) program, which takes the large-scale propfan (developed under the LAP program) and mates it with a gas generator and gearbox to form a propfan propulsion system and then flight tests this system on the wing of a Gulfstream II testbed aircraft.

Introduction

The propfan, a high speed, high efficiency aircraft propulsion concept was launched during the "Oil Crunch" days of the mid 1970's. In response to the national need to reduce fuel consumption, Congress directed NASA to address a series of aircraft related technologies aimed at increasing the fuel efficiency of airline operation. In response, NASA created the Aircraft Energy Efficiency (ACEE) program which addressed fuel savings through advancements in both airframe and engine technology. The element of the ACEE program offering the greatest potential fuel savings was the Advanced Turboprop Program.[1] Out of this element evolved the propfan concept.

Although high propulsive efficiency from turboprops was nothing new, the standards of high cruise speed and cabin comfort set by the contemporary turbofan powered aircraft were beyond the capability of any turboprop powered aircraft envisioned at that time. The concept which evolved to satisfy the requirements of high speed and altitude with improved efficiency while maintaining a high degree of cabin comfort is unlike any turboprop previously developed. It is characterized by the large number of blades (8 or 10), thin airfoil sections, and swept blade planforms (Fig. 1).

Once the concept and its benefits were identified on paper, NASA undertook a systematic approach to verify that the predicted benefits could be achieved and that there were no unsolvable problems in implementing the concept. For nearly 10 yr NASA and Hamilton Standard have cooperated in developing propfan technology. Until recently, this effort was chiefly through a series of 2 ft diameter scaled models which incorporated differing numbers of blades as well as changes in blade shapes. These models have been tested in several wind tunnels at NASA and United Technologies as well as on a NASA Jetstar acoustic research vehicle (Fig. 2). In these tests the targeted efficiencies were demonstrated, the source noise was characterized, and structural phenomena were identified. Detailed descriptions of these tests and results have been the subject of numerous technical papers; a summary of which can be found in Ref. 2.

Although the results of the aerodynamic performance, and source noise tests can be confidently scaled from model to product size, the structure of the solid homogeneous model blades is so different from that envisioned for production that extrapolation of structural behavior would be quite uncertain. The verification of the structural integrity of a large-scale propfan then becomes the final major technical hurdle to be crossed before industry acceptance of the Propfan as a viable aircraft propulsion scheme. This verification has been started in the Large-Scale Advanced Propfan (LAP) program in a variety of component tests and by tests of a full, 9 ft diameter rotor in a static rig and in a large high-speed wind tunnel. Experimental verification will be completed under the companion Propeller Test Assessment (PTA) program, where the large-scale propfan will be installed on an aircraft and flight tested.

This paper will discuss the content of the LAP program, progress made to date, and the planned experimental program through flight testing.

Overview of LAP Program

The LAP program is being conducted largely under a NASA Lewis Research Center contract with the Hamilton Standard Division of United Technologies. The major elements of the LAP program are depicted in the summary schedule shown in Fig. 3. Detail design and fabrication of the propfan components (blades, hub and blade retention, spinner, pitch change mechanism, pitch control, and instrumentation system) was initiated early in 1983 building on a preliminary design conducted under an earlier contract. Various bench tests of each component then follow to verify key design characteristics.

Design, fabrication, and test of an aeroelastically scaled 2 ft diameter propfan model is included in the program to obtain an early assessment of the propfan's aeroelastic characteristics. This model has been designated SR-7A and the large-scale propfan, SR-7L. Other objectives of SR-7A testing include the measurement of aerodynamic performance and noise.

Testing of the large-scale system includes whirl, static, and high-speed wind tunnel tests. Whirl testing is conducted in a Hamilton Standard facility to evaluate the hub, blade retention, and pitch change system. In these tests stub blades with counterweights are used to simulate blade loads. Final blades are then added to form a complete rotor assembly and this assembly is tested in the static propeller rig at Wright-Patterson Air Force Base (WPAFB) to assess rotational effects, stall flutter characteristics, and static performance. These static tests are followed by high speed tests in ONERA's S1 wind tunnel at Modane, France. These high speed tests will verify the propfan's aeroelastic characteristics at flight speeds up to Mach 0.85 and allow limited aerodynamic performance measurements to be made. Finally, two propfan assemblies will be delivered for flight testing under the companion PTA program.

Each of the elements of the LAP program will now be discussed in more detail, including an overview of the PTA program.

Large-scale Propfan Design

Design Requirements and Goals

To achieve the program objective of verifying large-scale propfan structural integrity, a number of design requirements and goals were established as summarized in Figs. 4 and 5. The requirements include characteristics judged essential to meeting the program objective as well as design features established from prior work. The goals, on the other hand, represent design targets and were judged less important to the program objective.

Of the requirements, the diameter of 9 ft was selected because it is sufficiently large to allow a blade construction which is representative of those planned for use on future transport aircraft (12-16 ft), and it is small enough to match the power of the largest available drive engine (Allison XT-701). The design point cruise Mach number and altitude were considered representative of modern transport aircraft, a primary application of propfans. The number of blades, tip speed, and power loading were determined from prior design tradeoff studies. In order to represent a configuration suitable for aircraft use, features such as icing protection and erosion protection are incorporated. The deicing system, however, will not be operational as no icing tests are planned. Finally, reverse thrust capability is included so that this operating mode can be evaluated in the program.

Of the design goals, the aerodynamic performance and noise values shown in Fig. 5 reflect preliminary estimates of what would be achievable in a large scale design. Stall flutter goals were established to avoid excessive blade stress at takeoff conditions. However, should this occur in LAP, it can be avoided operationally by limiting power until forward velocity increases sufficiently to eliminate the condition. The classical flutter goals were set to assure stable operation up to Mach 0.85 and 5 percent overspeed to allow for a broader range of test conditions. Stable operation at design speed in the ONERA S1 wind tunnel was also set as a design goal. The overspeed limit is a common requirement for propellers to insure adequate structural margin. The foreign object damage (FOD) goal reflects the FAA requirements for turbofans since there is currently no requirement for propellers. Finally, the blade life goals reflect target reliability and maintenance characteristics for production propfans.

In addition to the above requirements and goals, a design philosophy was adopted to focus on the fundamental issue of large-scale propfan structural integrity. In the case of the blades, blade retention, and hub, the key structural components of a propfan, existing state-of-the-art construction has been used. For other components, existing designs and parts are utilized where possible. For all components, conservative design margins were used to help insure the success of this first-of-a-kind propulsion concept.

A cutaway view of the resulting propfan assembly design is shown in Fig. 6. The design features eight (8) thin, swept blades constructed with an aluminum spar, foam filled fiberglass shell, nickel leading edge sheath and deicing heater. The hub is machined from a steel forging and the blade retention uses a single row ball design with a carburized outer race integral with the hub. The pitch change system allows for blade pitch adjustment in flight and utilizes a number of components taken from existing production systems. The pitch control is taken from a Hamilton Standard 54460 propeller (used on E2/C2 aircraft) and is modified to allow adjustment of the governing speed. The actuator is hydraulic, changes blade pitch through a scotch yoke mechanism, and incorporates a pitch lock concept taken from a Hamilton Standard commuter prop design. The pitch change system can also be assembled to allow direct blade pitch control, a feature useful in ground testing.

The spinner is a fiberglass/epoxy structure which is split along a circumferential line just aft of the blades for assembly. The spinner contour is area ruled to minimize choking losses in the blade root area.

The prop assembly also includes an instrumentation system for use in ground and flight tests. It features a 32 channel FM multiplex system which transmits strain gauge, pressure sensor, and blade angle sensor signals across a slip ring to a stationary recording system.

Blade Design

The origin of the LAP blade design traces back to a design study initiated in 1980 by Hamilton Standard under NASA Contract NAS3-22394 to assess the feasibility of large-scale propfan

blade designs. The study initially examined 11-ft diameter conceptual designs of the various experimental model configurations. These configurations involved a variety of shapes ranging from the straight bladed SR-2 to the highly swept SR-5. The results of the study helped to establish the feasibility of large-scale propfan blades as well as the structural tradeoffs to be considered in selecting the starting configuration for the SR-7L design.

Also evaluated in this study were blade construction concepts including hollow metal, solid composite, and spar/shell concepts. Of these, the spar/shell approach, used by Hamilton Standard in conventional propeller blade construction, was selected because of its damage tolerance, low weight, and advanced state of development.

The first step in the SR-7L design was an aeroacoustic tradeoff study where a variety of propfan design parameters were varied using a moderately swept blade, similar to the SR-3 model, as a baseline. The design parameters included power loading, tip speed, number of blades, blade sweep, thickness ratio, planform, lift coefficient, twist, and blade section stacking line position (on- versus off-helical surface).

The effects of these parameters were evaluated on an aircraft mission basis using sensitivity factors developed for a 120 passenger, twin engine airplane having a range of 1200 nmi and assuming a 500 nmi stage length.

In general, the study showed that a cruise, power loading of 32 SHP/D^2, tip speed of 800 ft/s and the assumed twist distribution were near optimum; and that increasing the number of blades, increasing sweep, decreasing thickness ratio, narrowing the blade (reducing activity factor), decreasing the lift coefficient, and stacking the blade on the helix were all aeroacoustically beneficial. However, the structural design work previously conducted showed that there are limitations to blade shape. Therefore, a compromise configuration similar to the SR-3 model was selected as a baseline for the structural design.

The structural design effort included over 60 configuration iterations. Trying to satisfy the requirements of low stress, no flutter, and satisfactory critical speed margins, while maintaining good aeroacoustic performance, proved to be a formidable task. A number of iterations involved adjustments to the blade section stacking line position (defined in terms of offset from the pitch axis for structural purposes). A distribution that was good for stress was bad for stability, and vice versa; and yet both requirements had to be satisfied. In the end, some reduction in sweep and increase in thickness was required over the baseline design to satisfy all requirements as shown schematically in Fig. 7.

The effect of the structural design process on design point aeroacoustic performance and fuel burned is summarized in Fig. 8. In spite of the compromises made to the blade shape, the net impact was a small increase in fuel burned over the baseline configuration. Aeroacoustic performance estimates for the final SR-7 design at other operating conditions can be found in Ref. 3.

The structural design analysis of the LAP blade included preparation of a detailed finite element model illustrated in Fig. 9. This model includes spar, foam filler, shell, and sheath layers and contains over 3000 elements. The model was used to generate the blade mode shapes and frequencies, stress and displacement distributions, and provide inputs to the flutter and impact analyses. Some of the key results are shown in Figs. 10 to 12.

The calculated modal frequencies for SR-7L at design cruise, takeoff/climb, and low RPM cruise are shown relative to the rotational frequencies in Fig. 10. The cross hatched areas are resonant conditions to be avoided in the design to prevent high cyclic stresses. These areas were avoided except for the second mode which marginally intersects the 3-P (three per revolution) avoidance area. This is not expected to be a problem as the excitations at this frequency are predicted to be weak.

A typical stress distribution is plotted in Fig. 11 for the design cruise condition. The stress values are shown as a percent of design allowable for high cycle fatigue and combines both steady and vibratory levels. As can be seen, all of the stresses at this selected condition are within acceptable levels. Both high cycle and low cycle fatigue were evaluated at a number of operating conditions to ensure satisfactory characteristics over the flight envelope.

The results of the classical flutter analysis are shown in Fig. 12 where the flight envelope is compared to the predicted stability boundary. Also shown is the predicted boundary for operation in the ONERA S1 wind tunnel. The wind tunnel boundary is displaced from the flight boundary due to temperature and loading differences. Adequate margin is indicated from these comparisons. Furthermore, it is believed that the prediction method[4] is conservative based on comparisons with model test data.

Other analyses were conducted to assess the adequacy of the design. They included an evaluation of the deflections under load (to assure that the blade has the proper shape at cruise), estimates of the stall flutter characteristics, and an analysis of the foreign object damage characteristics. The overall conclusion from the blade structural analyses was that the design was satisfactory and had sufficient margins to warrant proceeding with fabrication and testing.

Fabrication Status

Fabrication of the large-scale propfan has progressed on schedule with no major problems. All components for the first propfan assembly have been completed. Pictures of some of these components are shown in Figs. 13, 15, 16. The blade manufacturing sequence is illustrated in Figs. 13(a-d). First, an aluminum spar forging (Fig. 13(a)) is machined and shot peened. This

spar is then inserted in the foam mold (Fig. 13(b)) where polyurethane foam is injected to fill the leading and trailing edge cavities. The spar/foam subassembly is then wrapped with layers of dry fiberglass cloth to form the shell. At this time the leading edge sheath and deicing heater are installed. The blade assembly is then installed in the mold, epoxy resin is injected into the dry glass cloth, and the resulting assembly is cured (Fig. 13(c)). The blade is then removed from the mold and various trimming and finishing operations are performed, resulting in a completed blade as shown in Fig. 13(d).

A preliminary indication of the success of the blade design and fabrication process is shown in Fig. 14, where predicted static or nonrotating natural frequencies are compared to measurements for the first two blades. Agreement within 2 percent was found for modes one through five.

A finished hub is pictured in Fig. 15. The integral blade retention bearing races can be seen through the blade holes and the tailshaft, which will mate with a T-56 gearbox (used in the PTA drive system), extends to the right. This part was machined from a solid steel forging. The spinner assembly is pictured in Fig. 16 before painting. This molded fiberglass structure consists of a forward spinner with two internal stiffening ribs, the aft bulkhead, and eight removable tee plates which connect the forward spinner to the aft bulkhead.

Aeroelastic Model

The SR-7A model was designed to simulate the aeroelastic characteristics of the large-scale SR-7L blade under both steady and dynamic loading conditions. Specifically, the external shape was scaled down and mass and stiffness distributions were tailored, within manufacturing limitations, to produce steady deflections, resonant frequencies and vibratory mode shapes which match the large-scale blade.

SR-7A blades are constructed using a titanium spar, a fiberglass and graphite shell, and foam fill. Since the model does not incorporate a retention bearing, the spar has an elongate shank of reduced diameter to simulate the less stiff, large-scale retention. The shell is proportionately thicker than the large-scale blade to meet manufacturing requirements for injection molding. This left less room for the spar and resulted in a thinner, shorter spar. Graphite plys were added to the shell to compensate for the shorter, less-stiff spar.

A finite element analysis was conducted on SR-7A to determine how well its characteristics matched the large-scale blade. A comparison of mode shapes, as shown in Fig. 18, indicated the two designs are very similar. Predicted classical flutter boundaries also compared well.

A number of tests are planned for the model as outlined in Fig. 19. Tests similar to those conducted on the SR-5 model blade[5] are planned in United Technology Research Center's vacuum spin rig. In these tests blade stresses, frequencies, and deflections will be measured at various rotational speeds to confirm predicted effects of centrifugal forces alone (no air loads) on blade dynamics.

Both low and high speed wind tunnel tests of SR-7A on an isolated, axisymetric nacelle are planned at the Lewis Research Center. Aerodynamic and acoustic performance measurements will be made in these tests along with blade frequencies and deflections. Stall flutter characteristics will be assessed at static and low speed conditions and classical flutter at high speeds. The effect of angular inflow on blade stresses and performance will be measured at both low and high speeds.

High speed tests of the SR-7A propfan and nacelle installed on a wing are planned at the NASA Ames Research Center. These tests will primarily measure stress response of the blades to the distortions of an installed flow field for comparison to prediction. In addition, installed effects on aerodynamic performance will be assessed.

As of today, the SR-7A model has been fabricated and high speed aeroelastic tests were recently completed in the Lewis Research Center's 8- by 6-ft supersonic wind tunnel (Fig. 20). Testing was conducted at wind tunnel Mach numbers up to 0.90 and 105 percent design rotational speed with no evidence of classical flutter. Previous predictions had indicated that stability at the Mach 0.8 design speed in the Lewis wind tunnel was marginal. In addition, limited testing at near static conditions showed no evidence of stall flutter. These results add confidence that SR-7L will remain aeroelastically stable over the flight envelope.

Component Tests

A number of large-scale component tests are included in LAP to get early design confirmation and to measure those characteristics not easily obtained during system tests. These component tests are summarized in Fig. 21 and include blade tests, hub tests, and spinner tests.

Blade tests include vibration, stress distribution, fatigue, and FOD tests. In the vibration tests, mode shapes and frequencies are measured. Initial results from these tests were discussed earlier. The stress distribution tests involve the application of specified steady loads while measuring blade stress at critical locations on the blade to confirm analyses. Two types of fatigue tests will be conducted. In one, blades will be cantilever mounted and vibrated at resonant frequencies to produce various levels of cyclic stress. In the other, blades will also be cantilever mounted and vibrated, but an additional steady load will be applied to superimpose a mean stress on the cyclic levels. Both tests will be conducted in steps of increasing stress levels until four blades have failed in each series. Foreign object damage tests will be conducted both by dropping a simulated bird into a rotating blade and by pneumatically firing a simulated bird into a stationary blade. The FOD tests will include birds ranging in weight up to 4 lb.

The hub and spinner will be evaluated through vibration, stress distribution, and fatigue tests. Vibration tests will be conducted to determine natural frequencies of the hub and spinner and mode shapes for the spinner. Stress distribution testing for the hub involves applying steady centrifugal loads and bending moments to assess stress distributions. The bending moments will then be applied cyclically to verify adequate fatigue life. Spinner stress distributions will be measured during vibration testing and during spin tests which will include overspeed conditions. Verification of adequate spinner fatigue life will also be accomplished during vibration testing.

System Tests

Whirl Test

Rotating tests of the hub, blade retentions, and pitch change system will be conducted in Hamilton Standard's whirl rig. To stay within the limited power capacity of the rig's electric motor, stub blades and counterweights will be used to simulate centrifugal loads and twisting moments on the hub and pitch change actuator respectively. In the initial test series (just completed), the blade retention stiffness was determined by measuring the installed vibratory frequencies of the stub blades. Since these blades have known dynamic characteristics, the apparent retention stiffness can then be analytically deduced. Figure 22 shows a picture of the test installation and a front view of the prop assembly with stub blades. Preliminary results of the retention stiffness tests showed good agreement with design predictions. Subsequent functional testing of the pitch change system will verify its ability to respond to pitch change commands and produce adequate pitch change torque over the full range of speeds and blade angles. A number of pitch change cycles will be included in the tests to assure satisfactory life and reliability. Checkout of the hub-installed, instrumentation system will also be accomplished during these tests.

Static Rotor Test

Tests of the complete SR-7L propfan rotor will be conducted in the static propeller rig at Wright Paterson Air Force Base. A superimposed photo of a propfan installed on the rig is shown in Fig. 23. The rig is driven by a 10 000 hp variable speed electric motor.

The tests will map out any regions of stall flutter or stall-induced limiting stresses over a range of blade-tip speeds, blade angles (including reverse thrust), and power levels. Overspeed testing, up to 120 percent of design speed, will be conducted to verify structural margins. Blade deflections will be measured to confirm predicted effects of rotational loads. Static thrust and pressures (steady and unsteady) on the blade surfaces will also be measured for comparison to analysis.

High Speed Rotor Test

Following the static rotor test, the propfan will be tested in the ONERA S1 wind tunnel facility at Modane, France. A diagram of the propfan installed in the test section is shown in Fig. 24. This facility was selected for three reasons. First, it is capable of reaching high cruise Mach numbers. Second, it is sufficiently large (26 ft diam test section) to avoid excessive wall interference effects; and third, it has an existing model drive system. Although the power capability of the drive is only about one fourth of what the propfan is designed to absorb, proper blade loading can be reached by running with a partial set of blades (eight, four, and two blade configurations will be tested).

One purpose of the test is to conduct a careful and controlled search for any evidence of classical flutter. Because of the greater air density of the wind tunnel, it is possible to more closely approach the flutter threshold than at the 35 000 ft flight altitude. At design Mach number the wind tunnel operates at an effective altitude of about 14 000 ft. Analytic predictions and tests of the SR-7A model strongly suggest that classical flutter will not be encountered.

A second objective of the test is to measure steady and unsteady surface pressures on the blade as well as overall propfan performance. One blade will be instrumented with nearly 300 static taps (15 chordal and 10 radial stations on each side of the blade) to obtain a complete pressure map. Another blade will have 30 dynamic pressure sensors (7 chordal and 2 radial stations) to assess unsteady effects. These measurements should provide benchmark data for understanding the physics of transonic flow over the blades and for verification of analytic codes.

A final major objective of this test is to determine the structural and aerodynamic response of the propfan to angular inflow. Analysis of data from this simple, known angular inflow condition will significantly contribute to the understanding of propfan behavior in the more complex, airplane installed flow field.

Flight Test Program

Propfan hardware fabricated under the LAP program will be delivered to Lockheed Georgia Co., the prime contractor for the NASA Propfan Test Assessment (PTA) program as outlined in Fig. 25. The PTA program mates the 9 ft diameter LAP Propfan with a modified gas generator and gearbox supplied by Allison Gas Turbines, a division of General Motors Corporation. This propulsion unit will be assembled into a quick engine change (QEC) nacelle (fabricated by Rohr Industries) and the entire QEC will then be tested in a static test stand at Rohr's Brown Field facility. This initial propulsion system testing provides a checkout of the functional operation of the integrated propfan and engine system as well as an initial evaluation of the stall flutter characteristics of the propfan under cross-wind conditions.

Concurrent with the large-scale system build-up are 1/9-scale, aircraft model tests in wind tunnels at NASA Langley. These tests will confirm predicted aircraft stability and control, performance and flutter characteristics with the propfan system installed on the wing. Also measured will be flow field at the propfan plane of rotation.

At the conclusion of the static testing, the QEC will be mated with the wing of a Gulfstream II aircraft (Fig. 26) which will ultimately serve as the flight test vehicle for the Propfan. The engine/propfan/wing assembly will be placed in the 40x80 low speed wind tunnel at the NASA Ames facility where, in the presence of a simulated fuselage, aerodynamic and acoustics testing will be performed. Especially significant in this testing is the planned work to investigate cabin interior noise and the mechanism by which noise from the propfan is transmitted to the cabin interior airborne verses structure borne.

Following the Ames low speed testing, the wing with propulsion system is mated to the Gulfstream II flight research aircraft (by Gulfstream), in preparation for the flight phase of the PTA program. During this final phase of the PTA effort (currently scheduled to begin early 1987), propfan structural and acoustic (near and far field) data will be gathered and analyzed over the entire aircraft operating spectrum from static, thru taxi and into flight up to 0.83 Mach number and 40 000 altitude. In addition, noise levels will be measured in the aircraft cabin, initially with bare cabin walls and later with advanced noise suppression concepts installed, to confirm that a satisfactory cabin environment is achievable.

Concluding Remarks

The large-scale propfan program has been traced from its design origin through component and system ground tests to installation on an aircraft for flight testing. The data from all of the testing will provide a verification of the acceptability of the propfan system for use in future transport aircraft. Structural integrity of a large-scale propfan will be verified, and satisfactory cabin interior and community noise levels will be confirmed. With this information, industry will be in a position to conduct tradeoff studies to define a best configuration for future aircraft development. With the successful completion of the LAP and PTA programs, there should be no barriers to prevent the development and utilization of this advanced propulsion concept.

The systematic building block approach followed in the LAP and PTA programs allows the key characteristics of each component and system to be verified under known, well controlled conditions prior to operation in the more complex, less controlled flight environment. Through this process, maximum use can be made of the flight data in verification and improvement of design methodologies. It is believed that the large-scale data base and theoretical insights gained from the program will be applicable to all high speed, multiple-swept-bladed propeller concepts whether they be single rotation, counter rotation, tractor, or pusher.

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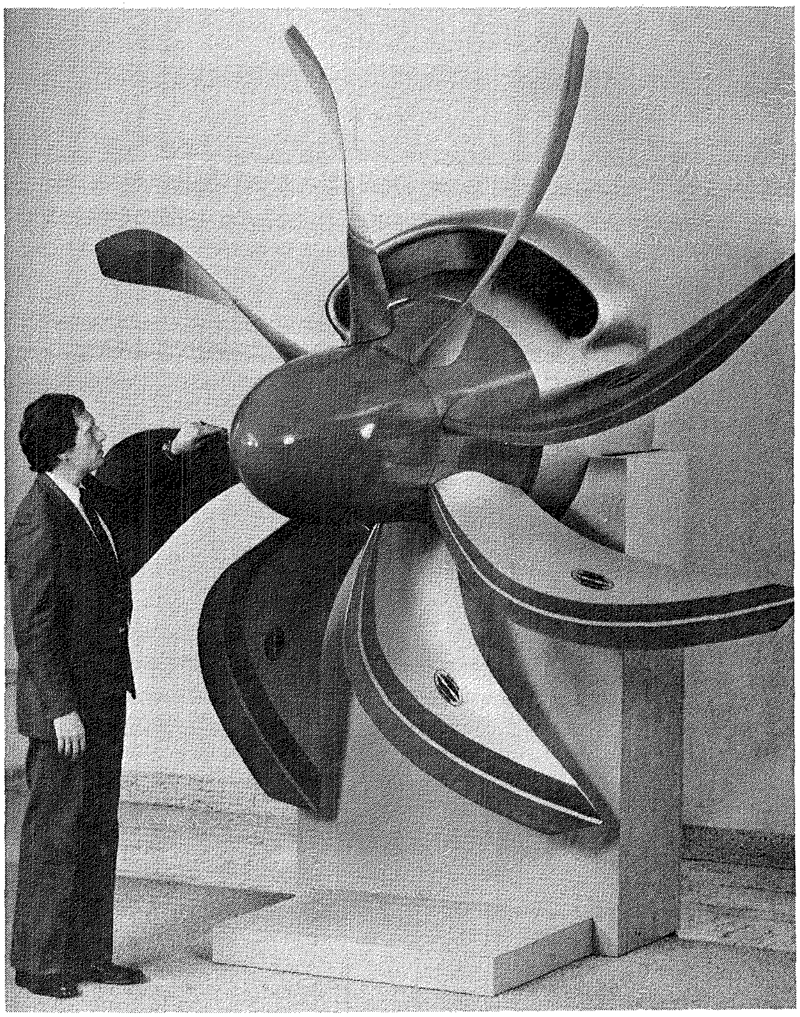
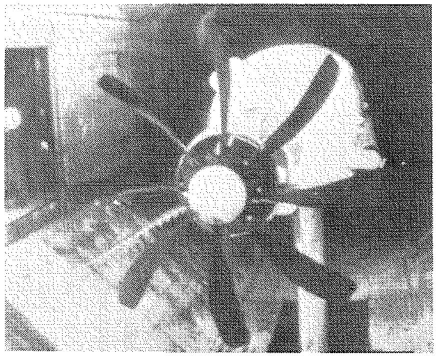
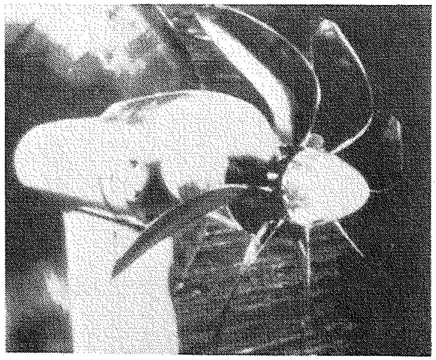


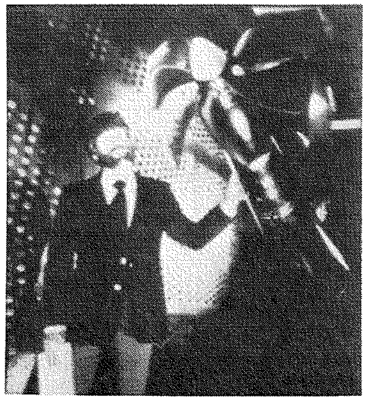
Figure 1. - Propfan concept.



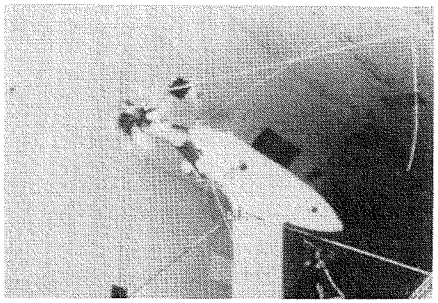
UTRC HIGH SPEED
WIND TUNNEL



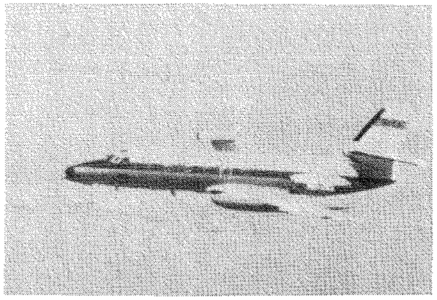
UTRC ACOUSTIC
WIND TUNNEL



NASA-LEWIS 8X6 SUPERSONIC
WIND TUNNEL



UTRC LOW SPEED
WIND TUNNEL



NASA JETSTAR

NASA-AMES 14 FOOT
WIND TUNNEL

Figure 2. - Single rotation propfan experimental programs.

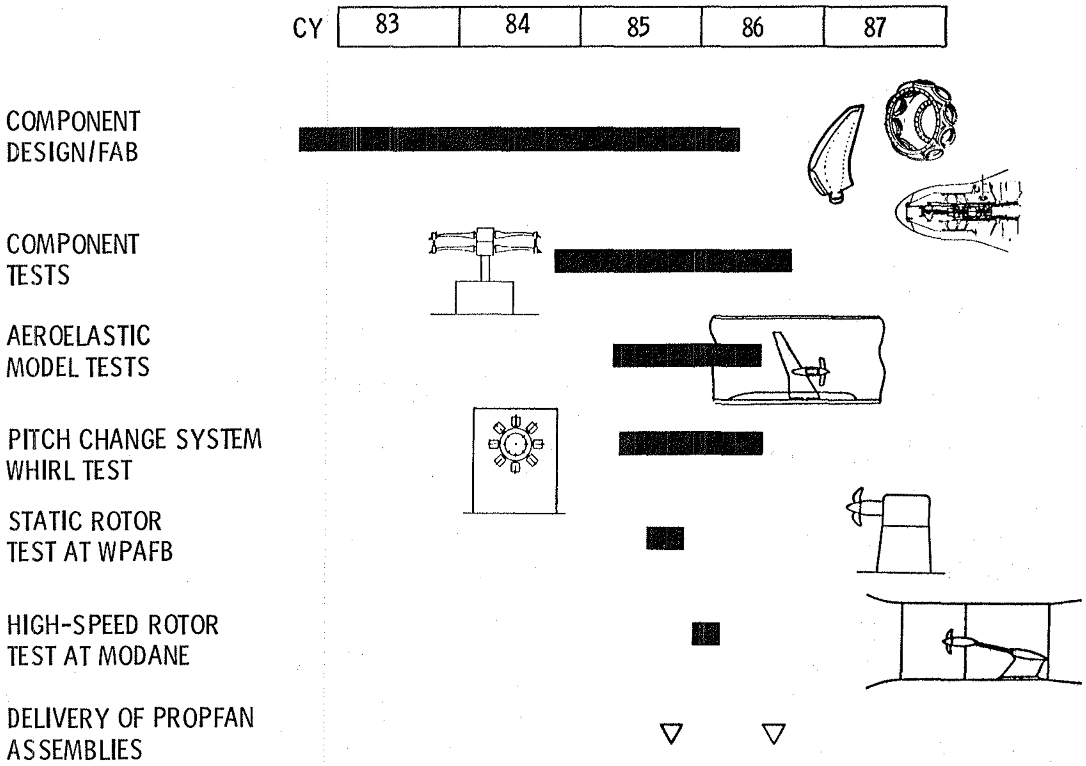


Figure 3. - Large-Scale Advanced Propfan (LAP) program elements.

CD-85-16622

- CONFIGURATION

DIAMETER	9 ft
NUMBER OF BLADES	8

- DESIGN POINT

CRUISE MACH NUMBER	0.8
ALTITUDE	35 000 ft
TIP SPEED	800 ft/sec
POWER LOADING ($SHP/_D2$)	32

- STRUCTURAL INTEGRITY

  FLUTTER FREE OVER NORMAL FLIGHT ENVELOPE ($M \leq 0.8$)
  STRESSES WITHIN ALLOWABLE LIMITS
  OVERSPEED TOLERANCE
  CRITICAL SPEED MARGINS

- SAFETY FEATURES

  LEADING EDGE PROJECTION
  LIGHTING PROTECTION
  ICING PROTECTION (INSTALLED BUT NOT OPERATIONAL)
  OVERSPEED PROTECTION

- REVERSE THRUST CAPABILITY

Figure 4. - Design requirements summary.

• NET EFFICIENCY (ISOLATED NACELLE)	- 78.6% AT M = 0.8, 35 000 ft (CRUISE) - 52.0% AT M = 0.2, SL (TO)
• NOISE	
NEAR FIELD (DESIGN POINT CRUISE, MAX. FREE FIELD, 0.8D)	- 144 db OVERALL SOUND PRESSURE LEVEL
FAR FIELD	- FAR 36 MINUS 10 db
• STALL FLUTTER	- NONE AT 100% TO POWER AND rpm; M = 0 - 0.2
• HIGH SPEED (CLASSICAL) FLUTTER	- NONE OVER EXTENDED FLIGHT ENVELOPE, ($M \leq 0.85$) 105% MAX OPERATING SPEED
• OVER SPEED LIMIT (HUB, BLADES, BLADE RETENTION)	- 120% MAX OPERATING SPEED - NO YIELD - 141% MAX OPERATING SPEED - NO FAILURE
• FOREIGN OBJECT DAMAGE	
MINOR - BIRDS UP TO 4 oz	- NO DAMAGE TO PRIMARY BLADE STRUCTURE
MODERATE - 2" HAIL; BIRDS TO 2 lb	- SOME LOSS OF MATERIAL OR AIRFOIL DISTORTION; OPERATE AT 76% POWER FOR 5 MINUTES
MAJOR - BIRDS UP TO 4 lb	- SOME LOSS OF MATERIAL OR AIRFOIL DISTORTION; MAINTAIN ABILITY TO FEATHER
• BLADE LIFE	- 35 000 hr - REPLACEMENT WITH SCHEDULED MAINT. - 50 000 hr - MEANTIME BETWEEN UNSCHEDULED REMOVAL

Figure 5. - Design goals summary.

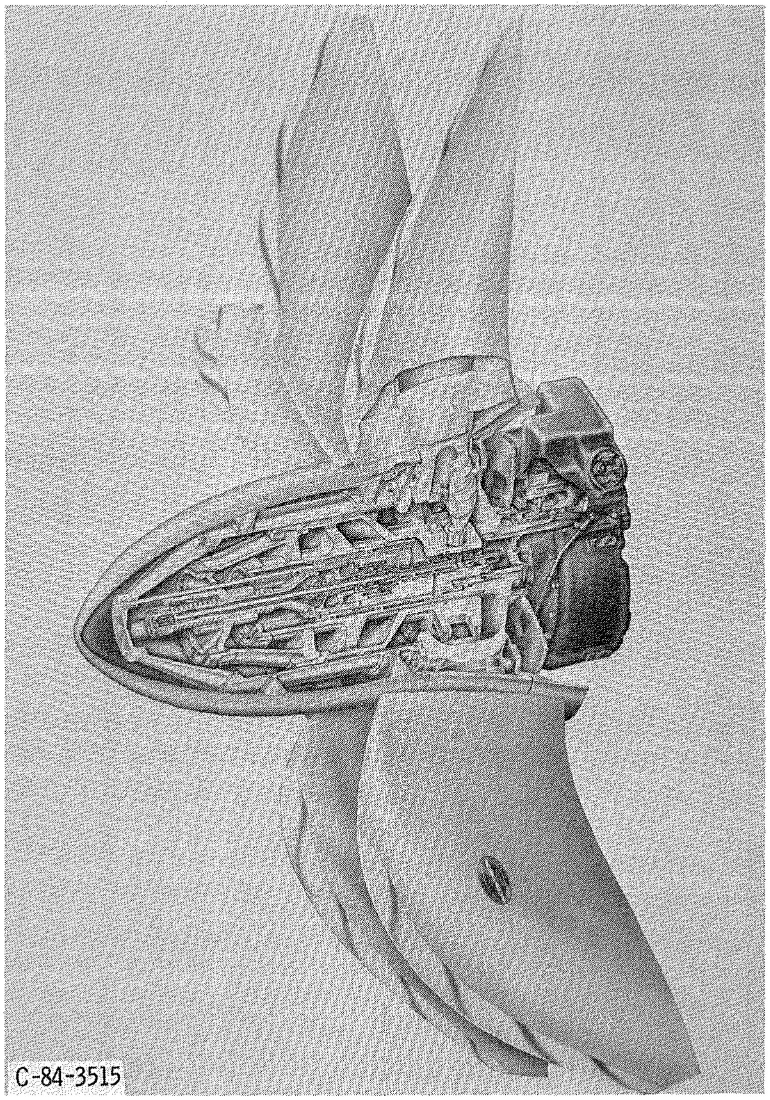


Figure 6. - Large scale SR-7L propfan.

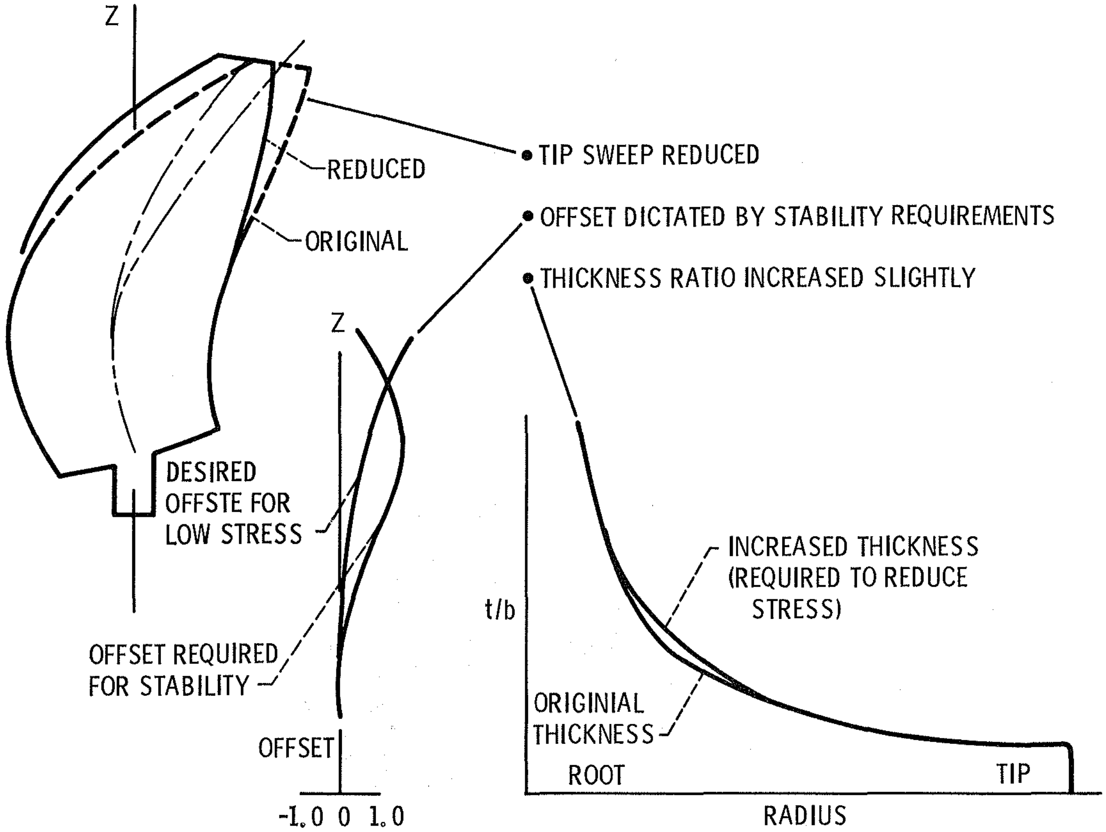


Figure 7. - Compromises for final SR-7L design.

- MACH 0.8
- 35 000 ft ALTITUDE
- 32.0 SHP/D^2 POWER LOADING
- 800 ft/sec TIP SPEED

	SR-7L BASELINE TO STRUCTURES	SR-7L FINAL
EFFICIENCY, %	79.6	79.4
NEAR FIELD NOISE, dB	141.9	143.0
Δ FUEL BURNED, %	0	+0.6

Figure 8. - Effect of design iterations on performance.

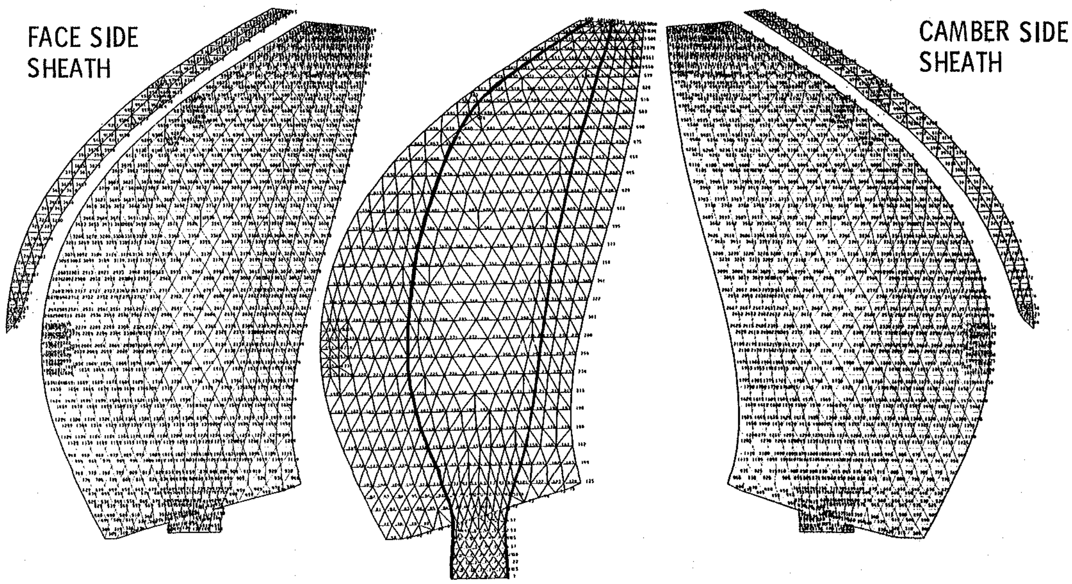


Figure 9. - Finite element analysis model layers.

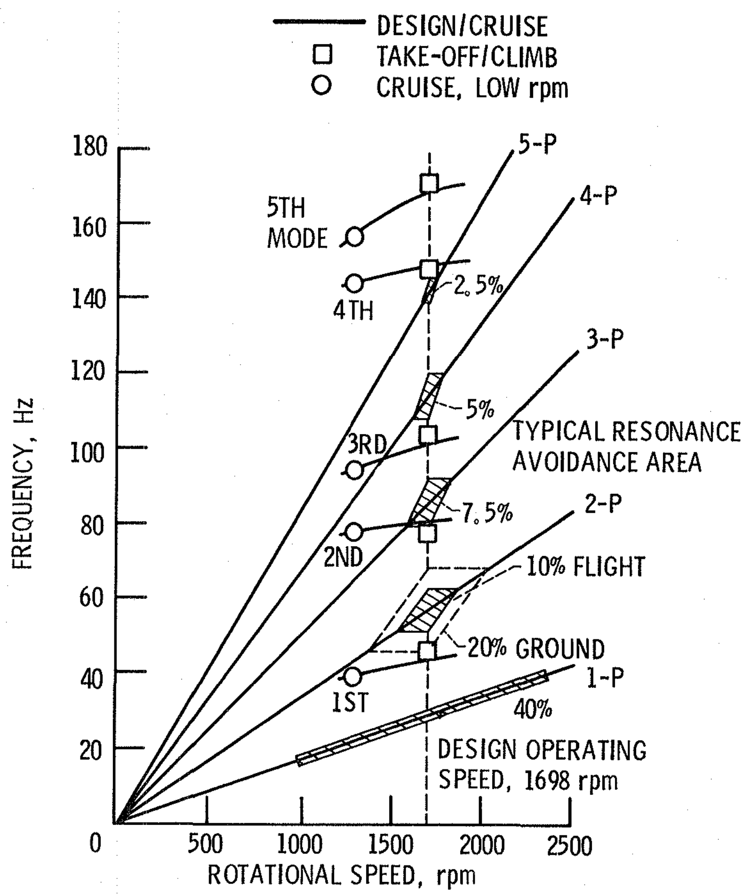


Figure 10. - Calculated SR-7L modal frequencies.

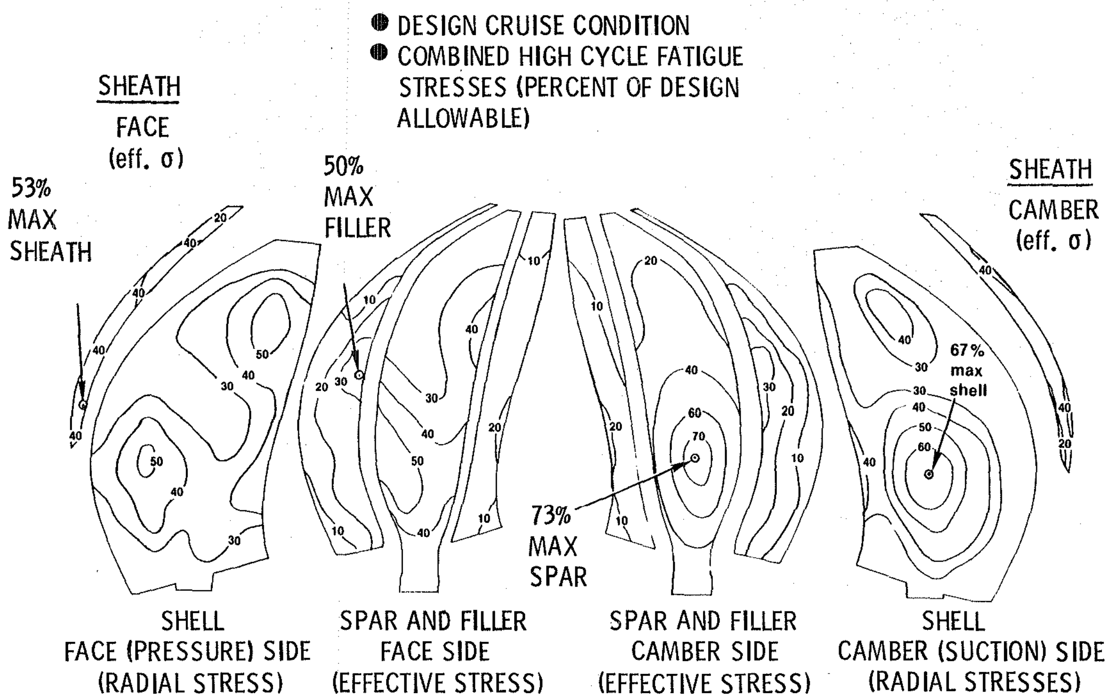


Figure 11. - Sample stress distribution.

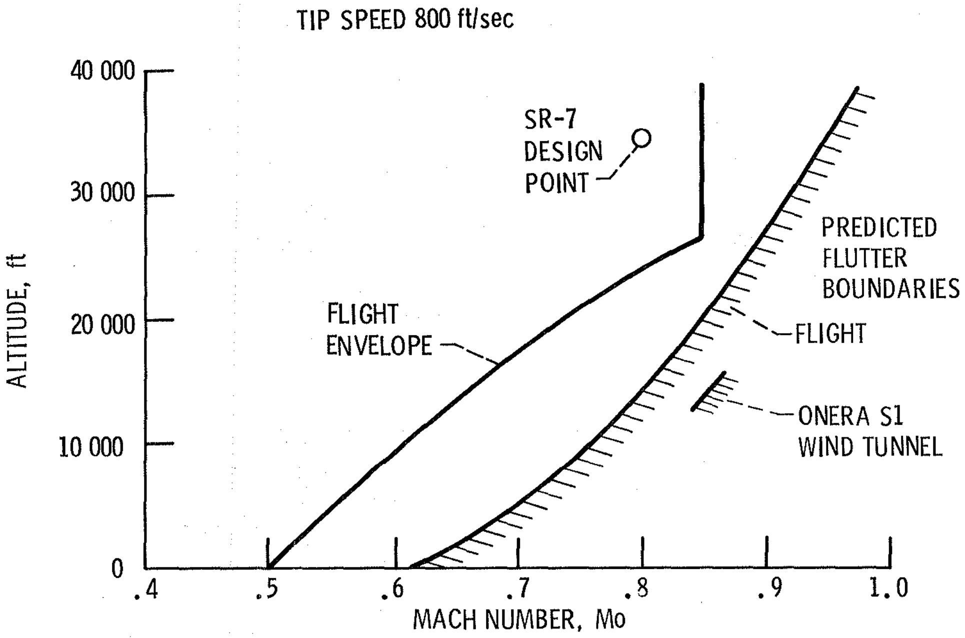
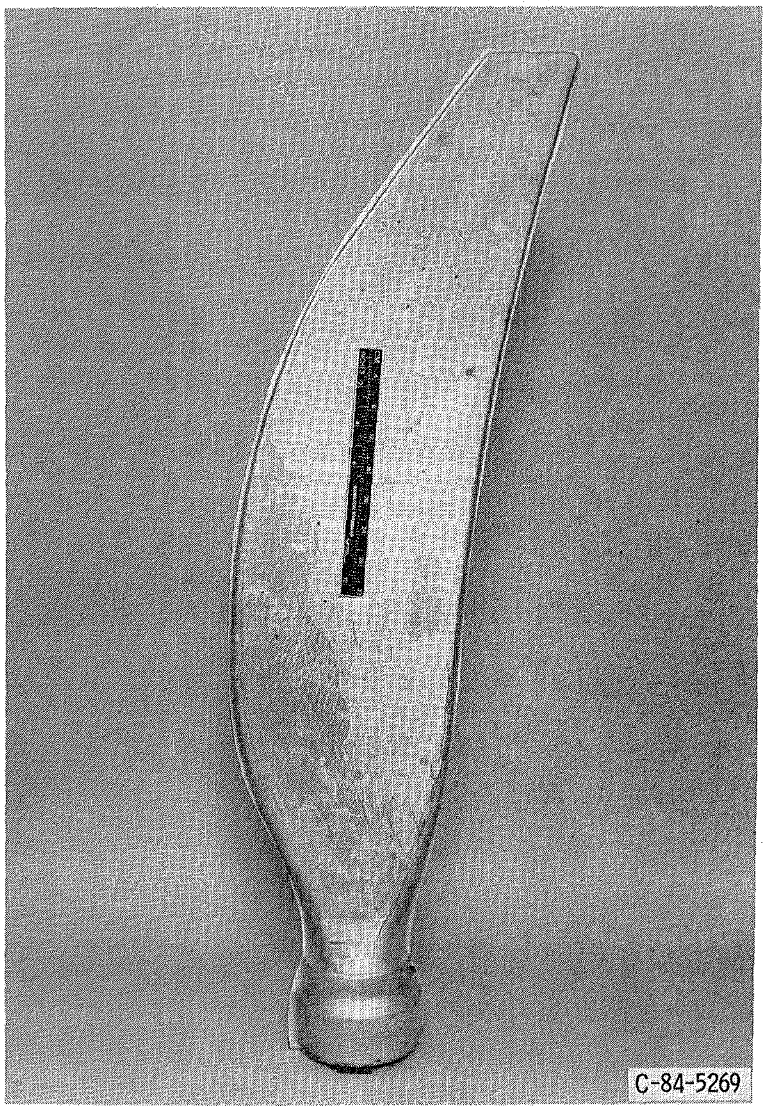
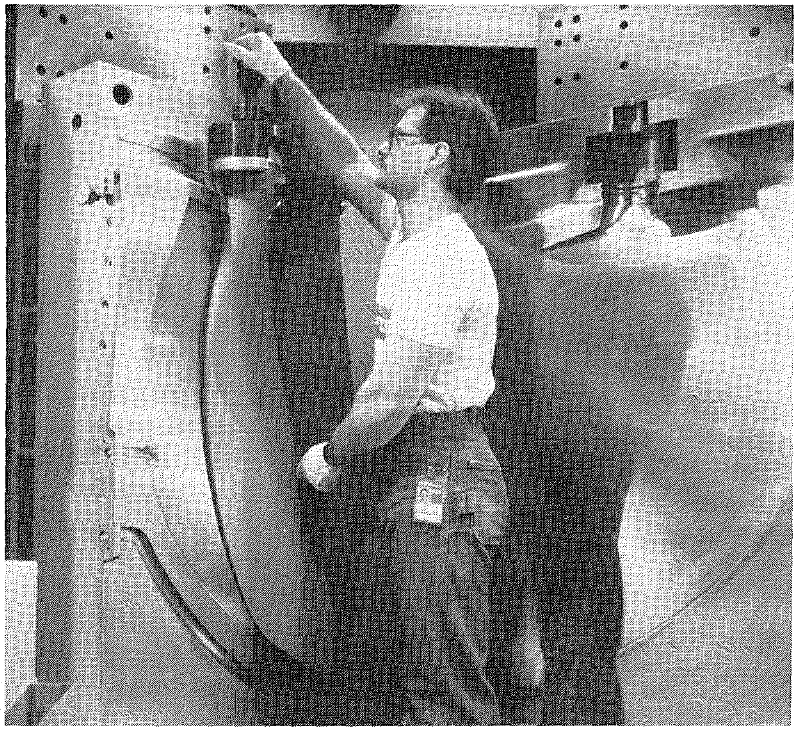


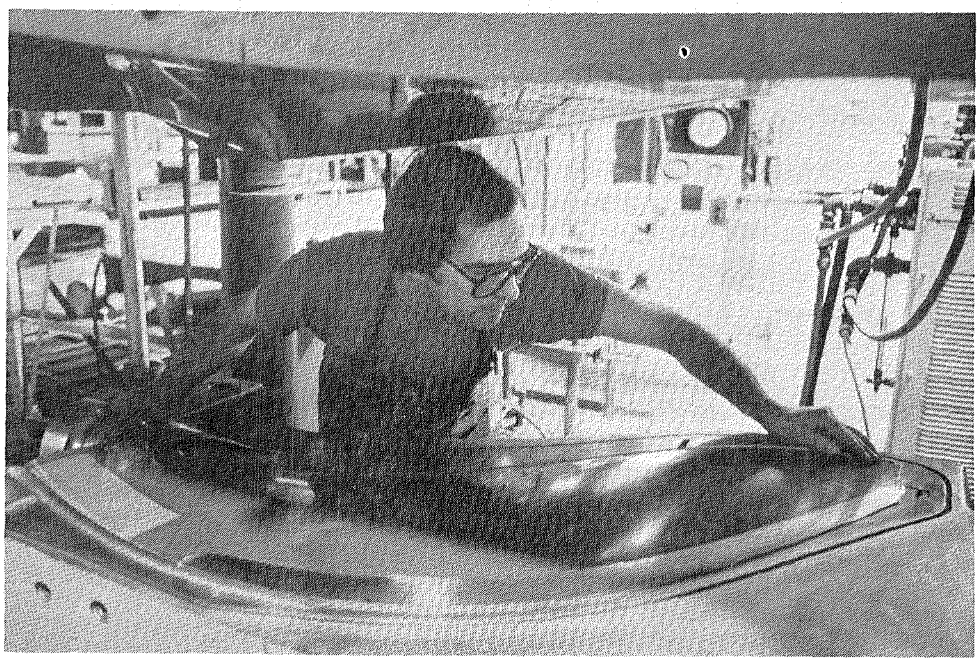
Figure 12. - Predicted SR-7L flutter characteristics.



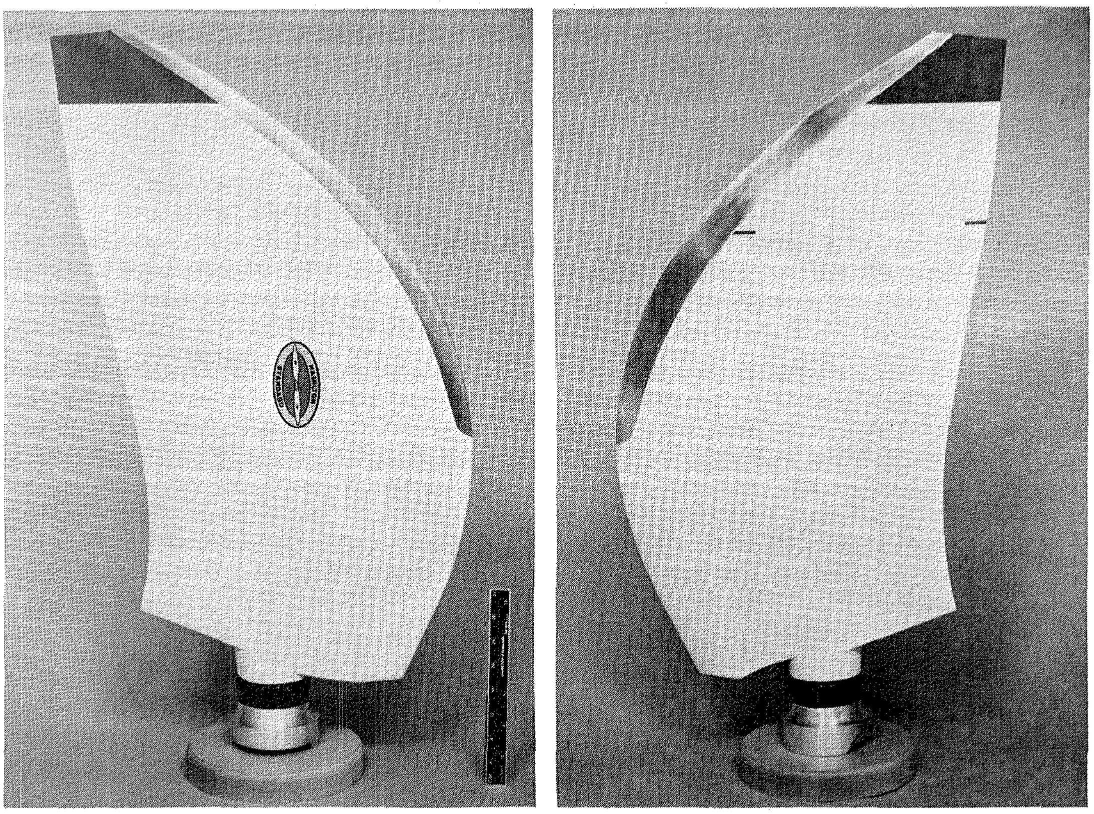
(a) Aluminum spar forging.
Figure 13.



(b) Spar foaming die.
Figure 13. - Continued.



(c)Blade resin injection die.
Figure 13. - Continued.



(d) Finished SR-7L blade.
Figure 13. - Concluded.

		MEASUREMENT	
MODE	PREDICTION	BLADE 1	BLADE 2
1	34	33.8	33.5
2	78	80.2	78.9
3	138	138.3	137.5
4	141	139.9	138.3
5	162	162.6	160.4

Figure 14. - SR-7L blade frequencies (non-rotating).

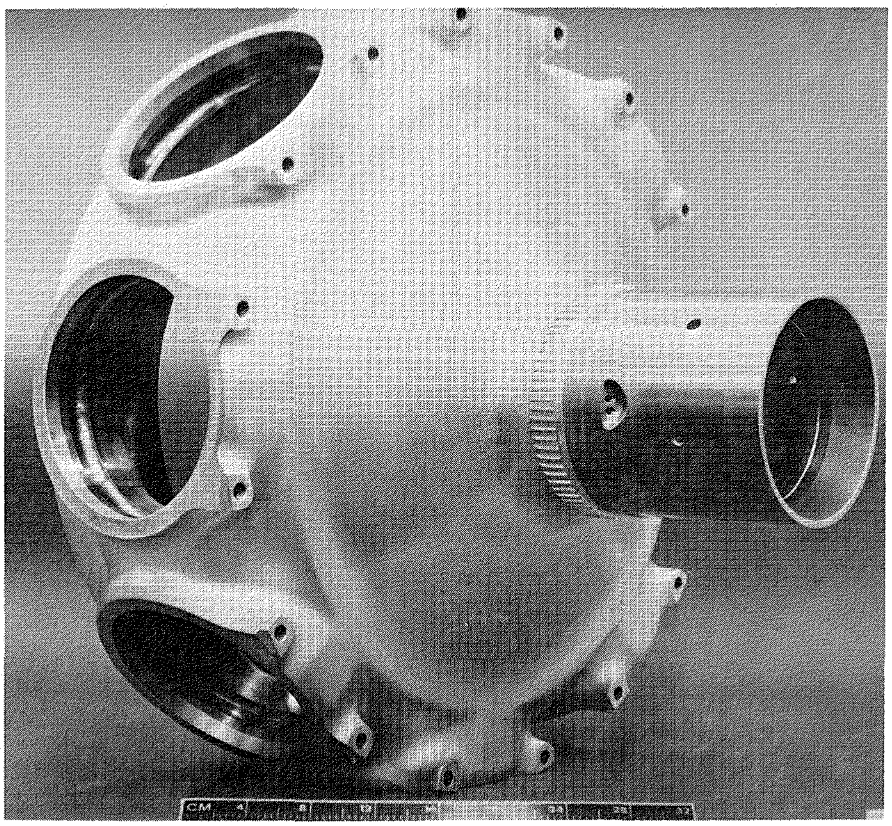


Figure 15. - SR-7L hub.

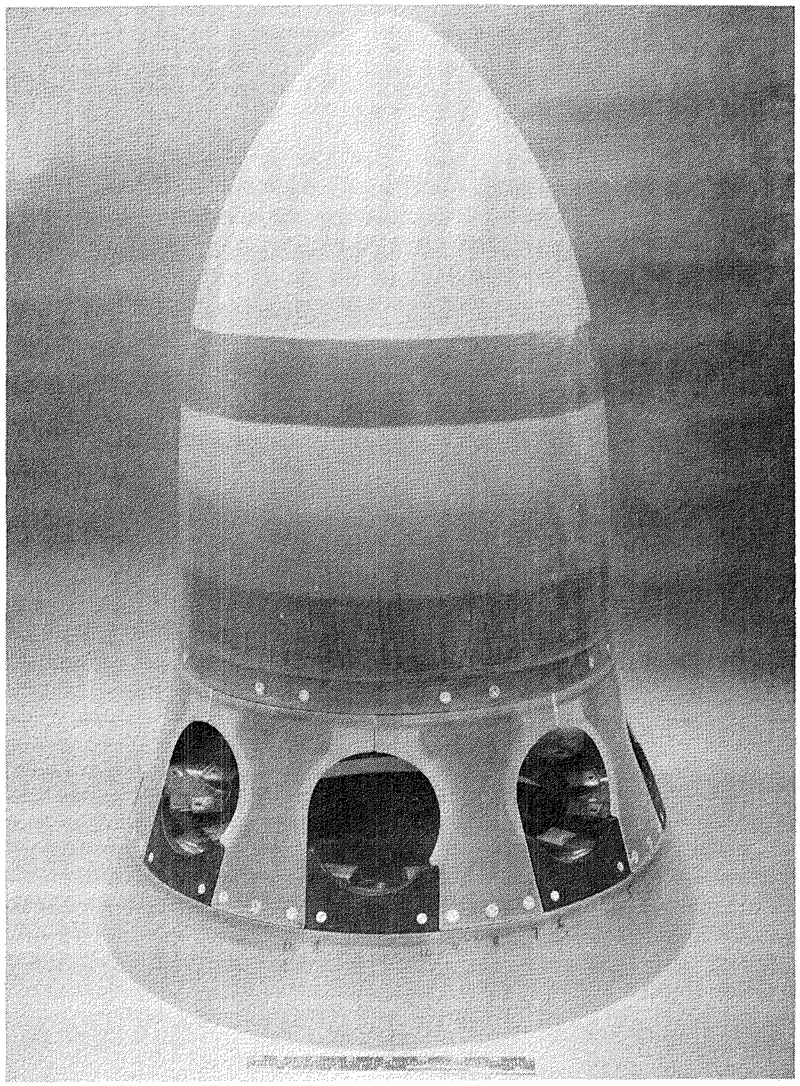


Figure 16. - SR-7L spinner.

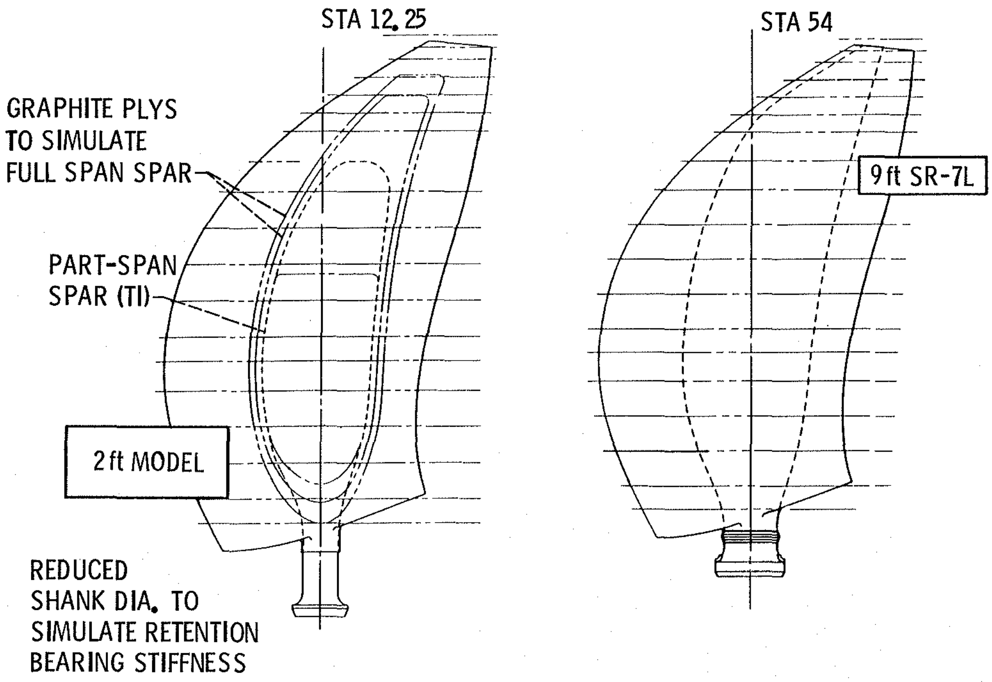


Figure 17. - Comparison of SR-7A aeroelastic model blade to full size.

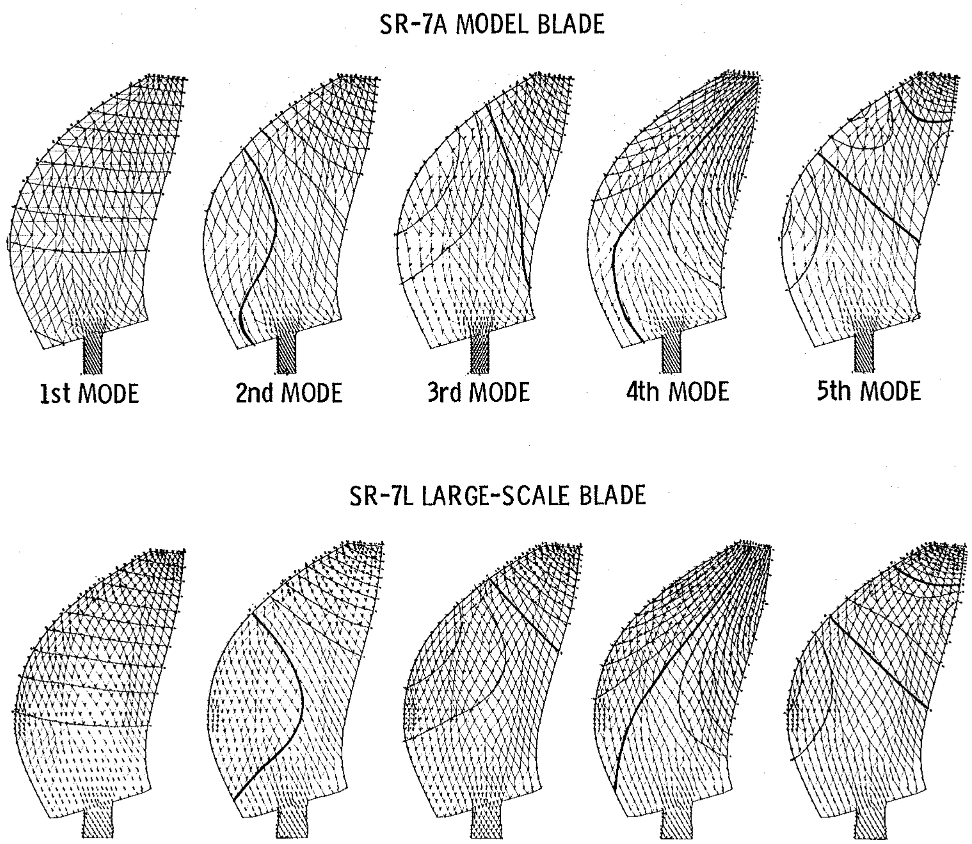


Figure 18. - Mode shape comparison.

	ACOUSTIC PERFORMANCE	AERODYN. PERFORMANCE	STALL FLUTTER	CLASSIC FLUTTER	BLADE STRESS	BLADE FREQ.	BLADE DEFLECTION	ANGULAR INFLOW EFFECTS
VACUUM SPIN PIT TESTS					X	X	X	
UNINSTALLED WIND TUNNEL TESTS	X	X	X	X	X	X	X	X
INSTALLED WIND TUNNEL TESTS		X		X	X			X

Figure 19. - Aeroelastic model test matrix.

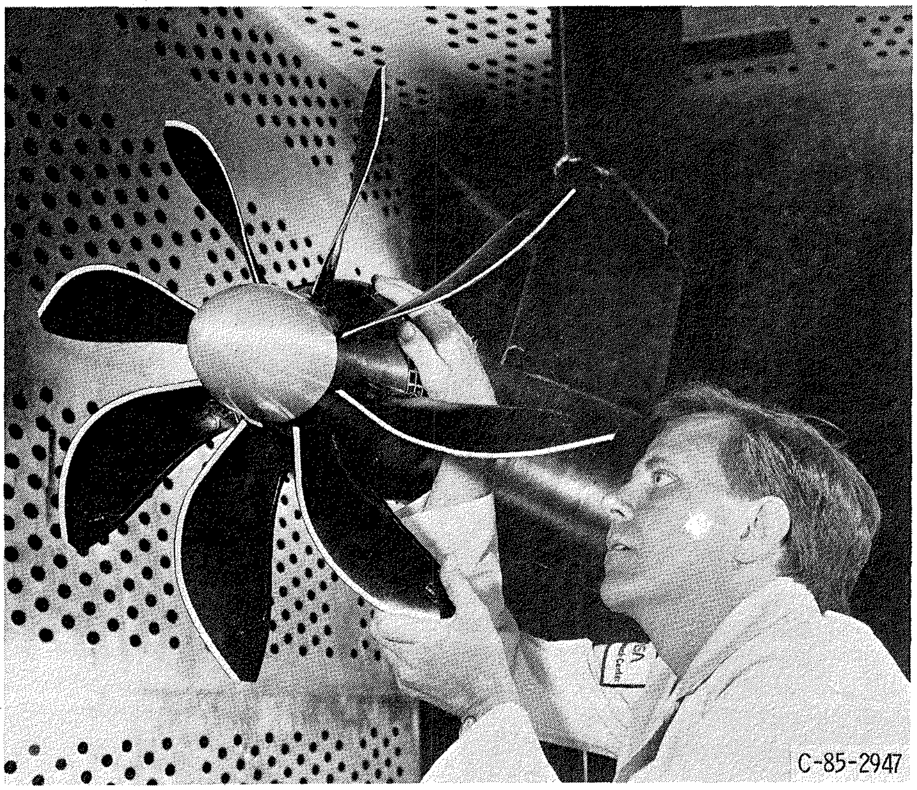


Figure 20. - SR-7A model installed in high speed wind tunnel.

	VIBRATION	STRESS DISTRIBUTION	FATIGUE	FOD
BLADE	×	×	×	×
HUB	×	×	×	
SPINNER	×	×	×	

Figure 21. - Large scale component test matrix.

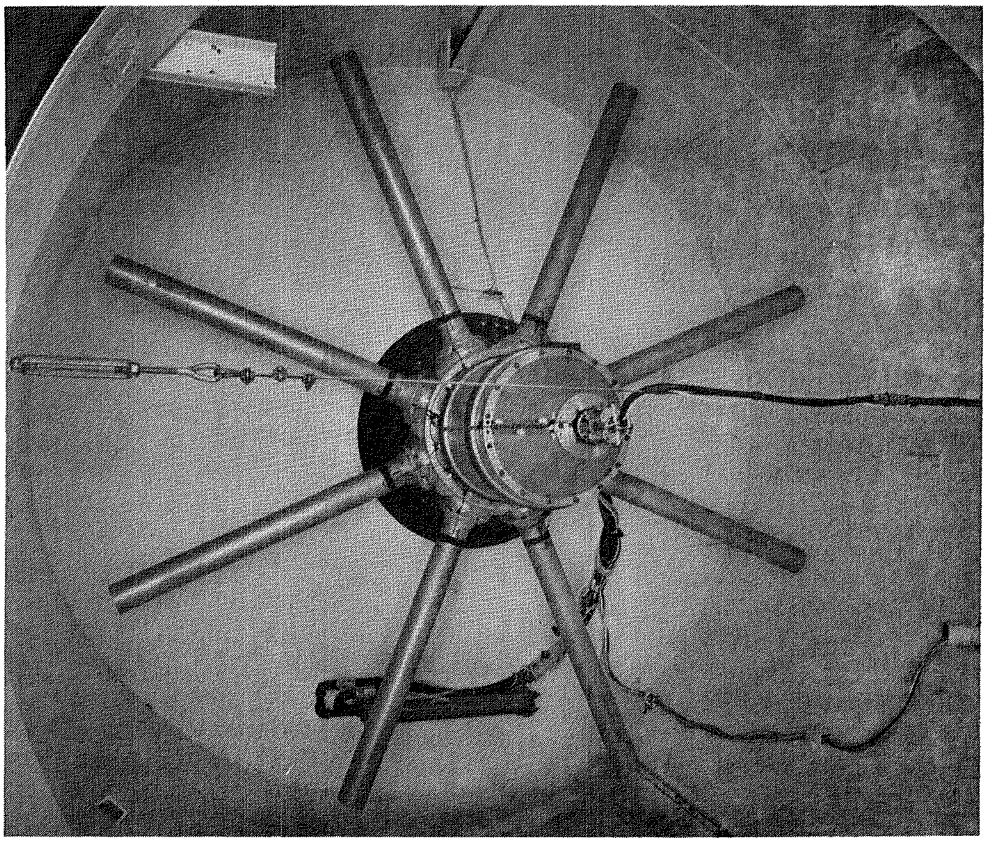


Figure 22. - Large scale whirl test installation.

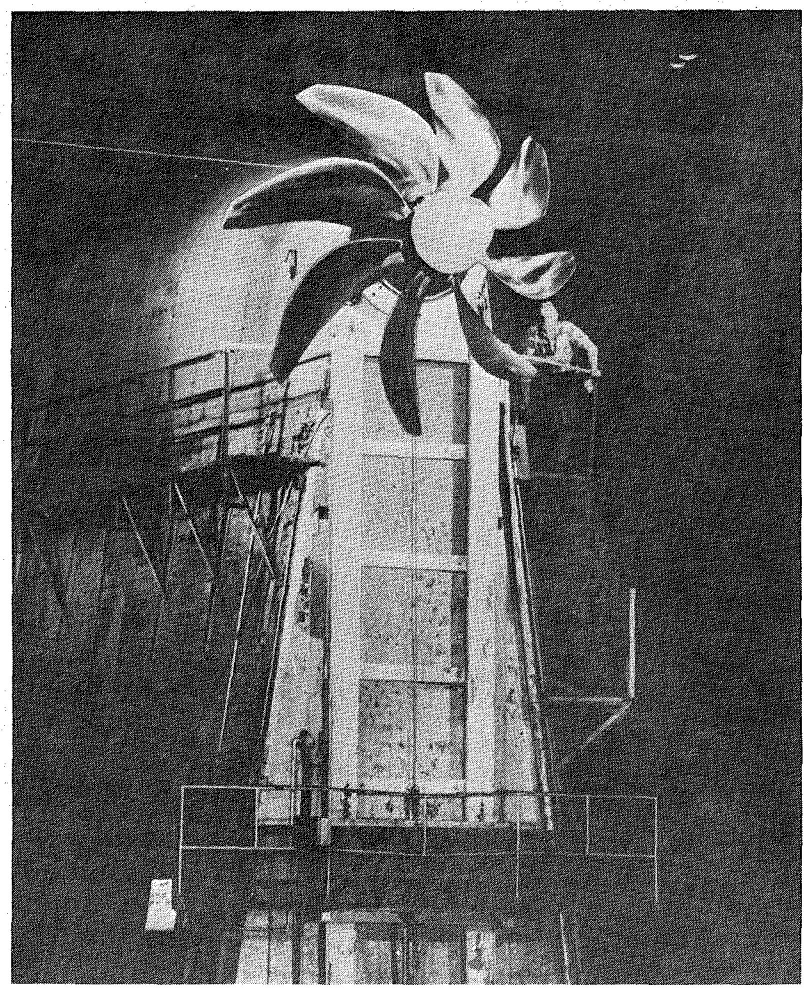


Figure 23. - Superimposed photograph of propfan installed in propeller test rig at WPAFB.

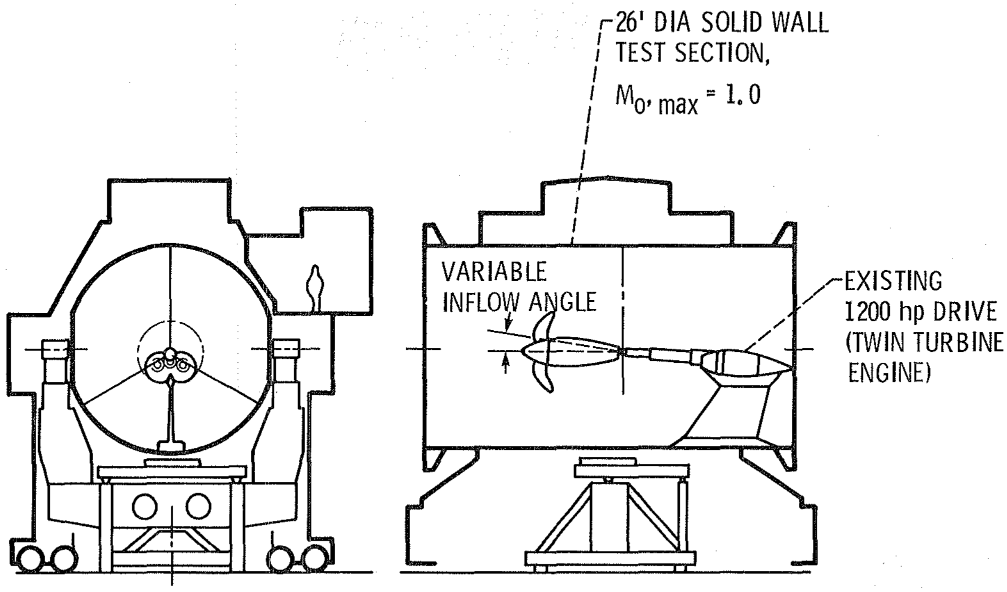


Figure 24. - Propfan installation in Onera S1 wind tunnel test section.

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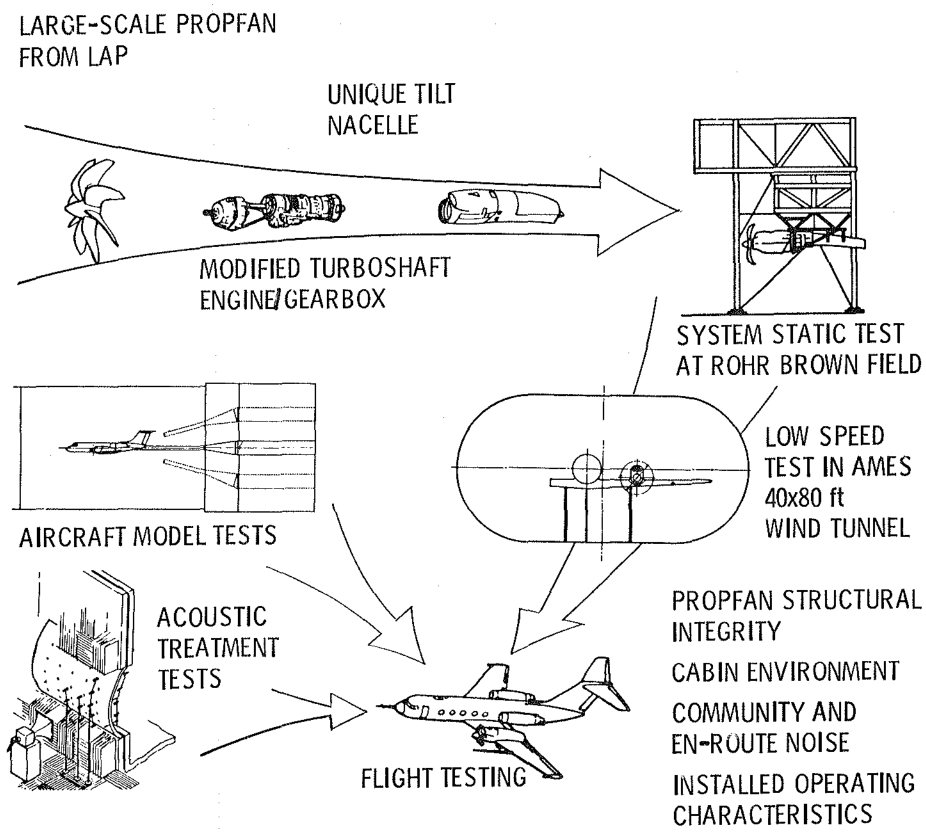

Figure 25. - Propfan test assessment (PTA) program elements.

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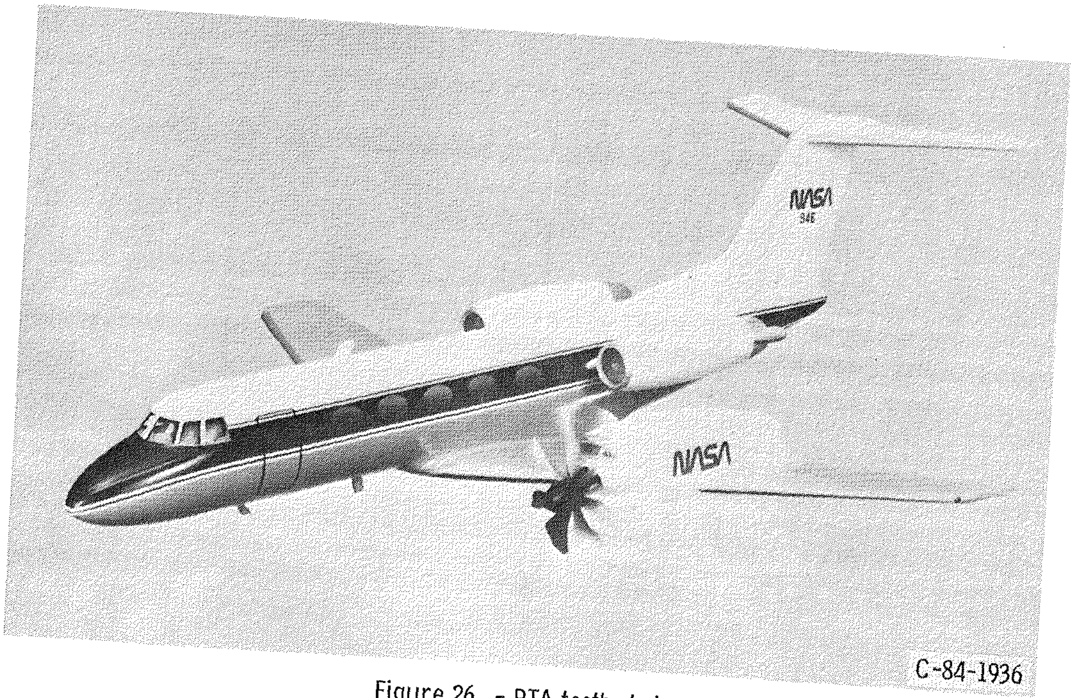

Figure 26. - PTA testbed aircraft.

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15. Supplementary Notes

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16. Abstract

The propfan concept, which has been the subject of much research since the mid 1970's, is an advanced propeller concept which maintains the high efficiencies traditionally associated with conventional propellers at the higher aircraft cruise speeds associated with jet transports. The Large-scale Advanced Propfan (LAP) program extends the research done on 2 ft diameter propfan models to a 9 ft diameter article which is representative of the size and construction that would eventually be installed on a new aircraft. This program includes design, fabrication, and testing of both an eight bladed, 9 ft diameter propfan, designated SR-7L, and a 2 ft diameter aeroelastically scaled model, SR-7A. The LAP program is complemented by another NASA sponsored program, the Propfan Test Assessment (PTA) program, which takes the large-scale propfan (developed under the LAP program) and mates it with a gas generator and gearbox to form a propfan propulsion system and then flight tests this system on the wing of a Gulfstream II testbed aircraft.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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